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Measurement of Ion Mobilities in Air and Sulfur Dioxide-Air Mixtures as a Function of Temperature

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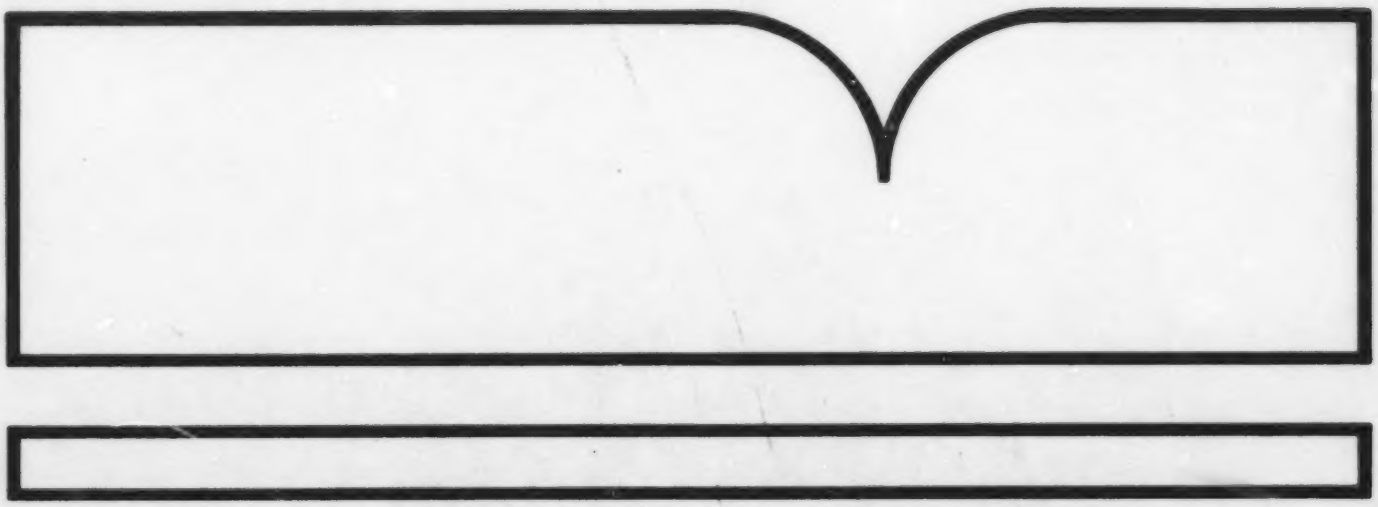

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16. ABSTRACT The paper discusses the measurement of ion mobilities for air with varying concentrations of water vapor and for dilute SO2/air mixtures. The conditions used were fairly comparable to those experienced in electrostatic precipitators (ESPs), both laboratory and full-scale units. The mobilities of the negative ions exhibited a fairly strong temperature dependence. The reduced mobilities for SO2/air mixtures were comparable to the reduced mobility for air. The results should be useful in ESP modeling applications.

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MEASUREMENT OF ION MOBILITIES IN AIR AND SULFUR DIOXIDE–AIR MIXTURES AS A FUNCTION OF TEMPERATURE*

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Abstract – Ion mobilities have been measured for air with varying concentrations of water vapor and for dilute sulfur dioxide–air mixtures. The conditions used were fairly comparable to those experienced in electrostatic precipitators, both laboratory and full-scale units. The mobilities of the negative ions exhibited a fairly strong temperature dependence. The reduced mobilities for sulfur dioxide–air mixtures were comparable to the reduced mobility for air. The results should be useful in precipitator modeling applications.

INTRODUCTION

Theories for modeling the performance of electrostatic precipitators depend upon knowing the mobilities of the ionic charge carriers (Cooperman, 1960; Leutert and Bohlen, 1972; McDonald *et al.*, 1977).

Quite often, the identity of the ions involved is completely unknown, and, since reduced mobilities for air ions have been reported over the range of $1.1–2.2 \times 10^{-4}$ m^2 V^{-1} s^{-1}, the model user is faced with considerable uncertainty in the appropriate value to use. Moreover, if the temperature for which the mobility was reported is different from the temperature of interest, there is little recourse but to use the ideal gas law to calculate a value (McDaniel and Mason, 1973). Finally, the mobilities of ions are not always measured in the appropriate environment; values quoted by Oglesby and Nichols (1978) are for ions in their parent gases, whereas in certain practical applications, mobilities of ions in air or an equivalent flue-gas atmosphere should be used.

Consequently, measurements were undertaken to establish more precise ion mobilities for use in electrostatic precipitator mathematical models. Negative ion mobilities were measured for air with varying degrees of humidity and for SO_2 in air; a positive ion mobility was measured for very wet air. No positive ions were observed for SO_2 in air.

EXPERIMENTAL

A Beta/VII Plasma Chromatograph† (PC) was used for the measurements. It is an ion-mobility spectrometer of the Bradbury–Nielsen type which computes mobility by means of the drift time of a pulse of ions moving under the influence of a constant electric field. Reviews of its operation have been published (Karasek, 1974; Revercomb and Mason, 1975). Gases were admitted to the PC, which can be operated at atmospheric pressure, and allowed to purge the instrument for several hours to establish equilibrium. The very dry air used was zero air (Matheson Zero Gas) which, after passing through the molecular sieve dryers of the PC, was estimated have less than 2 ppm water. Laboratory air was used for an intermediate moisture content and to simulate the gases seen in pilot and laboratory-scale precipitators. The estimated water content was 2%, based on the relative humidity of the laboratory. For high concentrations of water vapor, simulating flue conditions, laboratory air was humidified in a heated water bath to obtain 13% water.

The SO_2 was generated *in situ* by drawing laboratory air over a few μg of powdered sulfur in the inlet tube of the PC, which was maintained at 130°C; the concentration of SO_2 produced was estimated to be less than 10 ppm. For measurements of SO_2 in dry air, a commercial mixture was used (Scientific Gas Products), consisting of 10 ppm SO_2 and less than 8 ppm water. A distinct mobility peak was produced in the mobility spectrum when SO_2 was present and vanished when the SO_2 was purged from the system. Because of these observations, we called the ions in the peak SO_2 ions, although, for reasons given later, the ion identity is not certain.

Even at these low concentrations, the SO_2 ions nearly saturated the instrument, carrying 60–90% of the ion current. This ionization efficiency suggests that in full-scale precipitators, with SO_2 concentrations 100–1000 times higher, the entire current would be carried by SO_2 ions. The effect of these higher concentrations of SO_2 on the ionic mobility can

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be estimated by Blanc's law (McDaniel and Mason, 1973), using the value 0.41 × 10^{-4} m^2 V^{-1} s^{-1} for the reduced mobility of pure SO_2 (Oglesby and Nichols, 1978); the problem of ion identity still remains.

The identities of the actual ions carrying the current are not known for a number of reasons: the composition of trace gases in the laboratory air is not known; competing reactions for the formation of ions are not quantified; and clustering reactions are probably taking place. The mobility spectra for air were consistent with those in the literature (Carr, 1977; Spangler and Collins, 1975; Carroll *et al.*, 1975). The spectrum for SO_2 in laboratory air consists of a peak due to the presence of the sulfur and a separate distinguishable peak due to air ions. At higher SO_2 concentrations, the air ions are completely suppressed in competition with the SO_2 ions. Although the SO_2 peak is assumed to have SO_2^- ions as a main constituent, clustering of water molecules on the ions is also suspected. SO_3 would be expected to have a lower mobility due to the larger mass and cross-section of the ion, but no significant peaks of lower mobility were observed at the level of SO_2 used. In the commercial gas mixture, multiple peaks characteristic of dry air were observed along with a dominant single peak for the SO_2. The dominant peak was always accompanied by a smaller peak (5% as large) with a slightly smaller mobility, possibly due to SO_3.

Since interest was in the average mobility of all the current carriers, rather than in individual ion mobilities (except for SO_2), the total ion current for each case was integrated over all the ions, and the mobility corresponding to half the total current was calculated and used as the representative mobility. In the case of the intermediate and very wet air samples, this point corresponded closely to the peak in the spectrum. The spread in mobilities over the whole spectrum was less than 10% of the average mobility.

Measurements were made over a temperature range of 22°C–220°C, the maximum operating temperature of the PC. For all the samples used, it was found that the reduced mobility, μ_0, exhibited a temperature dependence. (This type of behavior has been observed for negative ions by Voshall *et al.* (1965) and Spencer (1975). The temperature dependence of the mobility for each sample was represented in the form of a power law:

$$\mu(T) = \mu_0(T/273.16)^{\beta}, \tag{1}$$

where T is in K and μ_0 is in m^2 V^{-1} s^{-1}.

RESULTS AND DISCUSSION

The results of the measurements are presented in Table 1, along with the standard deviations in μ_0 and β as determined by a least-squares fit. Arrhenius fits to the reduced mobilities were also tested and found to be somewhat inferior. Using the form:

$$\ln \mu_0(T) = A - B/T, \tag{2}$$

the coefficients were calculated. The activation temperature, B, and its standard deviation are also presented in Table 1.

The measurements on the negative ions reveal a definite trend. As the amount of water vapor present is increased, the reduced mobility of the ion decreases. This is consistent with the concept of increased clustering of water molecules around the ion as the water vapor pressure increases. The power law exponent also increases with water vapor concentration, which can be interpreted as a cluster-evaporation effect: the more molecules initially clustered, the more are shed as the temperature rises. The activation temperatures calculated from the Arrhenius fits also support this view. Experimental measurements of mobility temperature dependences and water clustering for positive ions have been recently reported by Kim *et al.* (1978).

The SO_2 exhibits a reduced mobility which is quite comparable to air, not considerably lower as reported in the literature (μ_0 = 0.41 × 10^{-4} m^2 V^{-1} s^{-1} from Oglesby and Nichols, 1978). The reason for this is that an ion in its parent gas experiences resonant charge transfer reactions which reduce its mobility substantially as compared with the ion in another gas where charge transfer is not possible. The fact that the power law exponent is greater than one, and that the reduced mobility decreases with increased water concentration, leads us to speculate that the observed ion represents a cluster, with some degree of hydration less than the air ions, based on the relative magnitudes of the temperature exponents and activation temperatures.

The positive ion mobility exhibits an anomalous behavior in that the temperature exponent is less than one and the activation temperature is negative. Because only a single broad peak is observed, there are undoubtedly several competing effects happening.

The drift time for these ions in the PC is of the order

Table 1. Measured ion mobilities

Species	$\mu_0 \times 10^4$, m^2 V^{-1} s^{-1}	β	Temperature range, °C	B, K
Negative ions				
Air, dry	2.092 ± 0.055	1.43 ± 0.04	25–160	174 ± 12
Air, 1.8% H_2O	1.768 ± 0.066	1.51 ± 0.06	22–200	182 ± 54
Air, 13% H_2O	1.578 ± 0.079	1.67 ± 0.08	60–220	301 ± 16
SO_2, 10 ppm in air, < 8 ppm H_2O	2.150 ± 0.007	1.12 ± 0.02	50–220	53 ± 3
SO_2 in air, 1.8% H_2O, about 10 ppm SO_2	1.876 ± 0.015	1.31 ± 0.01	60–220	127 ± 5
Positive ions				
Air, 13% H_2O	1.788 ± 0.059	0.81 ± 0.01	60–200	−73 ± 40

of 4–8 ms, with the drift tube field at 214 V cm^{-1}. In a precipitator, with electric fields two orders of magnitude higher, the drift times may be so short that ion clusters can not reach an equilibrium, leading to mobilities which differ from these low field values. Still, at high water vapor pressures, the equilibrium times will be very short (on the order of the time for several hundred or thousand collisions between the ion and water molecules). Also, the experimental data compiled by McDaniel and Mason (1973) show that many ions experience little change in reduced mobility from low field conditions to the moderately high field conditions typical of precipitators.

CONCLUSION

In conclusion, these measurements of ion mobility represent good values for use in electrostatic precipitator models. The negative ion mobilities for air are suitable for laboratory- and pilot-scale units at room temperature, or heated by a fuel with negligible sulfur, and the negative ion mobility for SO_2 may be suitable for full-scale units in certain cases. The temperature dependences of these mobilities should be used in preference to ideal gas law corrections. The positive ion mobility is included for its possible utility in modeling back corona effects.

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